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Handbook for Using Foams to Control Vapors from Hazardous Spills

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16. ABSTRACT

This handbook describes basic types of foams that may be used to control vapor hazards from spilled volatile chemicals. It provides a table to be used by spill response personnel to choose an appropriate foam based on the type of chemical spill. Six general types of foams are described; they are regular protein foams, fluoroprotein foams, surfactant (syndet) foams, aqueous film forming foams (AFFF), alcohol type or polar solvent type foams (ATF), and special foams such as Hazmat NF#1 which was developed especially for alkaline spills.

The handbook provides the basis for spill responders to evaluate and select a foam for vapor control by using the test methods presented or by considering manufacturers specifications for foam expansion ratios and quarter drainage times. The responder is encouraged to maximize the effectiveness of a foam by trying different nozzles, distances of applications, and thicknesses of the foam layers.

High-expansion (greater than 250:1 for the ratio of foam volume to initial liquid volume), mid-range-expansion (20-250:1), and low-expansion (less than 20:1) foams are discussed. Finally, suggestions for when, where, and how to apply foams for vapor control are presented.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory helps provide an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the Environmental Protection Agency; the granting of permits and other responsibilities of State and local governments; and the needs of both large and small businesses in handling their wastes responsibly and economically.

This handbook describes the selection and use of foams to control vapors from liquid hazardous material spills. The information presented in this report is intended to assist spill response personnel in deciding which foams to use with the various classes of spilled volatile compounds. During its preparation, this handbook has been thoroughly reviewed by experts on the use of foams. If warranted by users' demand, this information can be periodically updated. Therefore, we are soliciting users' comments, including information on any errors, suggestions for improvements, field experiences, introduction of new foams to field use, etc.

If you have such comments, please mail or phone them to:

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ABSTRACT

Firefighting foams are designed to control and extinguish fires involving a variety of flammable materials. However, recent research efforts have proven that foams are also useful in controlling vapors from spills of volatile hazardous materials. Moreover, some new, special foams have been designed for this purpose. This handbook contains a table to be used by spill response personnel to choose foams according to the types of chemical vapors they expect to encounter. Six general types of foams are described; they are regular protein foams, fluoroprotein foams, surfactant (syndet) foams, aqueous film forming foams (AFFF), alcohol type or polar solvent type foams (ATF), and special foams such as Hazmat NF #1, Hazmat NF #2, and MSA Type V.

The handbook provides the basis for spill responders to evaluate and select vapor control foams by using standard test methods for foam expansion ratios and quarter drainage times, or by comparing manufacturer's specifications for these parameters. The responder is encouraged to maximize the effectiveness of a foam by trying different nozzles, distances of application, and thicknesses of the foam layer.

High-expansion (greater than 250:1 for the ratio of foam volume to initial liquid volume), medium-expansion (20-250:1) and low-expansion (less than 20:1) foams are discussed. Finally, suggestions for when, where, and how to apply foams for vapor control are presented.

The handbook was reviewed before final publication by experts on the use of foams to ensure that up-to-date information was included. The handbook was submitted in fulfillment of contract No. 68-03-3113, Task 21-2 by Science Applications International Corporation (SAIC) under the sponsorship of the U.S. Environmental Protection Agency. This handbook covers a period from April 1984 to June 1985, and work was completed as of August 30, 1985.

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1. INTRODUCTION

The purpose of this handbook is to assist firefighters and other first responders in the selection and use of foams for the control of hazardous vapors. Although it is understood that the selection of firefighting foams will always be directed more toward fire control than toward vapor control, the information contained in this handbook should be used to select foams that can optimize responses to both fires and hazardous vapors.

Firefighters and other first responders are often confronted with chemical spills from storage tanks, tank trucks, and railroad tank cars that contain volatile hazardous materials. Firefighting foams are commonly used to blanket these materials, thereby greatly reducing the chance of fire or the potential for human injury or even death through inhalation of toxic vapors.

The mechanisms of vapor mitigation by foams are complex, and are specific to the chemical compounds involved. A complete description of these mechanisms is beyond the scope of this handbook, however. Foams generally function to block the surface of spilled materials, thus reducing volatilization of spilled chemicals. Foams can prevent boiloff of spilled chemicals by protecting the surface of a spill from heat produced by fires and solar radiation. Foams can reduce vapor concentrations above spilled liquids by over 90 percent, but vapor suppression is temporary, lasting between 5 to 120 minutes before reapplication becomes necessary.

Foams can be used to facilitate cleanup and surveillance at a chemical spill. However, the use of inappropriate foams on spilled chemicals may result in human injury through violent foam-chemical interaction, or in a wasted investment of money when a foam is destroyed upon contact with spilled chemicals.

It cannot be emphasized enough that vapors are suppressed at hazardous waste spills not only to control fire hazard, but also to prevent human or environmental exposure to toxic vapors. Understanding the basic capabilities of certain foams will promote the safe and effective control of vapors from spills of hazardous materials, and facilitate the collection of the spilled material.

2. TYPES OF FOAMS

Foams may be used to diminish or halt the generation of toxic or flammable vapors from volatile liquids or solids (1). There are six basic types of foams available for use on spilled volatile chemicals (2). These are regular protein foams; fluoroprotein foams; surfactant (synthetic) foams; aqueous film forming foams (AFFF); alcohol type or polar solvent type foams (ATF); and special foams, which are designed to control vapors from chemicals that would destroy conventional foams. In addition, new types of foams, called polymeric alcohol resistant foam and film forming fluoroprotein foam (FFFP), have been introduced (3). However, there are insufficient data on their vapor controlling qualities for inclusion in this handbook.

All foam types are designed for use with low-expansion foam-making equipment, which limits the expansion ratio (ratio of foam volume to liquid volume) to less than 20:1. However, surfactant foams can also be used with medium- and high-expansion foam-making equipment, which allows for expansion ratios from 20 to 1000:1 (4).

Foams are produced by mixing a foam concentrate with water and air under pressure. A container of foam concentrate is tapped by using a proportioning device, the simplest of which is an eductor. Proportioning devices range in complexity from the eductor to around-the-pump and balanced pressure proportioners (5). The proportioner is connected to a fire hose at a point upstream of the foam nozzle. The proportioning unit meters the proper amount of foam concentrate that is dispensed to the fire hose. The nozzle causes turbulent mixing of water with air just before the mixture exits as foam.

Foam concentrates are commercially available for a number of uses. The properties of the six basic foam types are discussed below.

2.1 Regular Protein Foams

Protein foam concentrates are composed of an animal protein (keratin hydrolyzate) with polyvalent cations and other stabilizing elements. Developed in the 1950's, protein foams are the oldest of the firefighting foams. These foams exhibit good resistance to reignition after extinguishing a fire, but they generally have poorer flowing ability and slower fire knockdown ability than other types of foams (6).

2.2 Fluoroprotein Foams

Fluoroprotein foams were designed for fast fire knockdown and long protection against the reappearance of flammable vapor concentrations above a spilled liquid. As a mixture of regular protein (keratin hydrolyzate) foam concentrate, AFFF, and polyvalent cations, fluoroprotein foams exhibit shorter fire knockdown times than regular protein foams and longer vapor control times than AFFF. However, fluoroprotein foams do not knock down fires as quickly as AFFF foams (6).

2.3 Surfactant Foams

Surfactant foam concentrates contain surface active agents (syndets). The extent of surfactant foam expansion depends primarily on the type of equipment used to produce the foam, but many surfactant foam manufacturers identify their products as being either low-, medium-, or high-expansion foams. Low-, medium-, and high-expansion foams use an eduction device to proportion foam concentrate into the water stream. High-expansion surfactant foams are produced by a device that blows the surfactant-water mixture through a screen to make bubbles. Low-expansion surfactant foams are seldom used because their resistance to burnback and their ability to knock down fires are exceeded by other low-expansion foams. High-expansion surfactant foams expand up to 1000 times the volume of the water entering the foam maker; however, the normal range of high-expansion foams is between 300 and 750 to 1. (See discussion of expansion ratios under "Foam Quality", Subsection 3.2) (7).

2.4 Aqueous Film Forming Foams

Aqueous film forming foam (AFFF) concentrates are made from mixtures of fluorocarbon surfactants and conventional surfactants and are designed for fast knockdown of hydrocarbon fires. Developed in the 1960's, these AFFF foams generally lose their water of composition more quickly after application than other foams, and flammable liquids tend to be less resistant to reignition after they have been blanketed by AFFF. These foams derive their name from a thin film that develops over liquid surfaces that are sprayed with AFFF. This film impedes the escape of toxic and flammable vapors (8).

2.5 Alcohol Type Foams

Alcohol type foams (ATF) were developed to extinguish hydrocarbon and polar solvent (water miscible) fuel fires. They consist of an AFFF, regular protein, surfactant, or fluoroprotein base concentrate with either a metal stearate additive (salt of stearic acid) or a polymeric additive. When ATF foams are applied to polar solvents, the additive coalesces into a gel, forming an insoluble, low-permeability skin which inhibits vapor release (1).

The stearate-based foams were developed earlier and have shorter shelf lives and poorer flowing abilities than polymeric-based ATFs.

2.6 Special Foams

In addition to the above-mentioned types of foams, there are at least three foams that were specifically formulated to control hazardous vapors. These are Hazmat NF #1, Hazmat NF #2, and MSA Type V. Hazmat NF #1 and NF #2 are designed to be effective against alkaline and acid spills, respectively. MSA Type V is used to control vapor hazards from water-reactive volatile chemicals, and has a pH tolerance between 2 and 10 (6, 8, 9, 10). These foam concentrates have special additives that allow them to be used on materials that would destroy other foams. More manufacturers are planning to develop foams especially formulated for controlling hazardous vapors.

3. SELECTION OF FOAMS FOR VAPOR CONTROL

This section provides guidance to select appropriate foams to use on chemical spills and discusses the qualities that should be considered in selecting particular brands of foams. Table 1 provides a rating of foam types for use on specific chemicals based on literature and personal communications from manufacturers and researchers referenced in this handbook.

3.1 Foam Types

The selection of the appropriate foam type for use at a spill can make the difference between a substantial reduction of risk from vapor ignition, explosion, toxic effects, and an undesirable increase in risk associated with unfavorable foam-chemical interactions. For example, application of an AFFF foam to a spill of liquefied natural gas is not only a waste of expensive foam, but it results in increased boiloff of flammable vapors (1,6,11). Similarly, any foam type other than an alcohol foam is wasted on a polar solvent spill, and only a high-expansion surfactant foam should be used to control silicon tetrachloride vapors (1). These examples do not imply that only one type of foam will work in each spill situation. However, for every different spilled chemical, there are usually one or two types of foams that exceed the vapor mitigating potential of other foam types. In addition, many chemicals, particularly those that are inorganic and water-reactive, can be more dangerous when blanketed with the wrong foam than they are in the absence of foam application.

Table 1 indicates appropriate foam types for controlling vapors produced by specific compounds. The table was constructed by compiling available information from literature on the use of foams for controlling vapors from hazardous substances (1,11-26). Much of this literature provides test results on the performance of various foam types on specific chemicals. The left hand columns of Table 1 identify the chemical groups and substances for which data were found in the literature (see references). The chemical groupings are provided only as a means of organizing the chemicals in the table. Use of foams on chemicals not listed in the table is not recommended unless the foam manufacturer provides test data on the use of a specific foam on a given chemical.

The next two columns of the table provide the "recommended" and "satisfactory" foam types for use on each identified chemical. These columns were developed from vapor control test results that were often reported as visual observations made by researchers. Therefore, the table reflects test results that are somewhat subjective (compared to a numerical ranking of foam performance with standard criteria).

TABLE 1. FOAM SELECTION CHART FOR CONTROL OF HAZARDOUS VAPORS

GROUP	CHEMICAL (DOT No.)	RECOMMENDED FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	SATISFACTORY FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	INEFFECTIVE/ DANGEROUS FOAM TYPES (Reason)
ALCOHOLS	Butanol (Butyl Alcohol) (1120)	Alcohol (ND**)	None	AFFF (collapse) Fluoroprotein (collapse) Protein (collapse) Surfactant H&L***(collapse)
	Methanol (1230)	Alcohol (ND)	None	AFFF (collapse) Fluoroprotein (collapse) Protein (collapse) Surfactant H&L (collapse)
	Octanol	Alcohol (ND)	AFFF Fluoroprotein Protein Surfactant H&L	
	Propanol (1274)	Alcohol (ND)	None	AFFF (collapse) Fluoroprotein (collapse) Protein (collapse) Surfactant H&L (collapse)
ALDEHYDES AND KETONES	Acetone (1090)	Alcohol (10/60)	None	AFFF (collapse) Fluoroprotein (collapse) Protein (collapse) Surfactant H&L (collapse)

(continued)

TABLE 1 (continued)

GROUP	CHEMICAL (DOT No.)	RECOMMENDED FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	SATISFACTORY FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	INEFFECTIVE/ DANGEROUS FOAM TYPES (Reason)
ALDEHYDES AND KETONES (cont.)	Methyl Butyl Ketone (1245)	Alcohol (ND)	None	AFFF (collapse) Fluoroprotein (collapse) Protein (collapse) Surfactant H&L (collapse)
	Methyl Ethyl Ketone (1193)	Alcohol (ND)	None	AFFF (collapse) Fluoroprotein (collapse) Protein (collapse) Surfactant H&L (collapse)
AMINES	Ethylamines (1036)	Alcohol (ND) Hazmat NF #1 (ND)**** MSA Type V (ND)	None	AFFF (collapse) Fluoroprotein (early breakthrough) Protein (collapse) Surfactant H&L (collapse)
	Ethylene Diamine (1604)	Alcohol (ND) Hazmat NF #1 (ND) MSA Type V (ND)	None	AFFF (collapse) Fluoroprotein (early breakthrough) Protein (collapse) Surfactant H&L (collapse)

(continued)

TABLE 1 (continued)

GROUP	CHEMICAL (DOT No.)	RECOMMENDED FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	SATISFACTORY FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	INEFFECTIVE/ DANGEROUS FOAM TYPES (Reason)
AMINES (cont.)	Hydrazine (2029) or (2030)	Alcohol (ND) Hazmat NF #1 (ND) MSA Type V (ND)	None	AFFF (collapse) Fluoroprotein (early breakthrough) Protein (collapse) Surfactant H&L (collapse)
	Methylamines (1061) or (1235)	Alcohol (ND) Hazmat NF #1 (ND) MSA Type V (ND)	None	AFFF (collapse) Fluoroprotein (early breakthrough) Protein (collapse) Surfactant (collapse)
ETHERS	Ethyl Ether (1155)	Alcohol (5/25-120)	None	AFFF (collapse) Fluoroprotein (collapse) Protein (collapse) Surfactant (collapse)
ESTERS	n-Butyl Acetate (1123)	AFFF (5/120) Alcohol (5/120) Fluoroprotein (5/120) Protein (5/120) Surfactant L (5/120)	None	Surfactant H (no information)

(continued)

TABLE 1 (continued)

GROUP	CHEMICAL (DOT No.)	RECOMMENDED FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	SATISFACTORY FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	INEFFECTIVE/ DANGEROUS FOAM TYPES (Reason)
ESTERS (cont.)	Methyl Acrylate (1919)	Alcohol	None	AFFF (collapse) Fluoroprotein (collapse) Protein (collapse) Surfactant H&L (untested)
	Vinyl Acetate (1301) (monomer)	Alcohol (ND) Fluoroprotein	AFFF (ND)	Protein Surfactant H&L
HYDRO-CARBONS (ALI-PHATIC)	Ethane (1961)	Surfactant H	Alcohol (ND) Fluoroprotein (ND) Protein (ND) Surfactant L (ND)	AFFF (acceierates boil-off)
	Ethylene (1038) (1962)	Surfactant H	Alcohol (ND) Fluoroprotein (ND) Protein (ND) Surfactant L (ND)	AFFF (accelerates boil-off
	Heptane (1206)	Alcohol Fluoroprotein (ND) Protein (ND) Surfactant H&L (ND)	AFFF (ND)	None

(continued)

TABLE 1 (continued)

GROUP	CHEMICAL (DOT No.)	RECOMMENDED FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	SATISFACTORY FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	INEFFECTIVE/ DANGEROUS FOAM TYPES (Reason)
HYDRO-CARBONS (ALI-PHATIC) (cont.)	Hexane (1208)	Alcohol	AFFF (ND) Fluoroprotein (ND) Protein (ND) Surfactant (ND)	None
	Octane (1262)	Alcohol (50/90)	AFFF (5/60) Fluoroprotein (5/60) Protein (5/60) Surfactant L (5/60), H (ND)	None
HYDRO-CARBONS (AROMATIC)	Benzene (1114)	Alcohol (2.5/120)	Fluoroprotein (5/60) Protein (5/60) Surfactant H (25/50)	AFFF (early breakthrough) Surfactant L (early breakthrough)
	Ethylbenzene (1175)	AFFF (5/120) Alcohol (5/120) Fluoroprotein (5/120) Protein (5/120) Surfactant L (5/120)	Surfactant H (50/30)	None
	Toluene (1294)	Alcohol Fluoroprotein Protein	AFFF (5/40) Surfactant H (50/30) Surfactant L (5/30)	None

(continued)

TABLE 1 (continued)

GROUP	CHEMICAL (DOT No.)	RECOMMENDED FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	SATISFACTORY FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+min.)*	INEFFECTIVE/ DANGEROUS FOAM TYPES (Reason)
HYDRO-CARBONS (ALI-CYCLIC)	Cyclohexane (1145)	Alcohol (5/>120) Fluoroprotein (5/>120) Protein (5/>120)	AFFF (5/60) Surfactant H (ND) Surfactant L (5/30)	None
HYDRO-CARBONS (INDUS-TRIAL)	Gasoline (1203)	Alcohol (ND) Fluoroprotein (ND) Protein (ND) Surfactants (ND)	AFFF (ND)	None
	Kerosene (1223)	Alcohol (ND) Fluoroprotein (ND) Protein (ND) Surfactants (ND)	AFFF (ND)	None
	Naphtha (2553)	Alcohol (ND) Fluoroprotein (ND) Protein (ND) Surfactants (ND)	AFFF (ND)	None
	Paint Thinner (1263)	Alcohol (ND) Fluoroprotein (ND) Protein (ND)	AFFF (ND) Surfactants (ND)	None

(continued)

TABLE 1 (continued)

GROUP	CHEMICAL (DOT No.)	RECOMMENDED FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	SATISFACTORY FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	INEFFECTIVE/ DANGEROUS FOAM TYPES (Reason)
LIQUEFIED ORGANIC GASES	Ethylene Oxide (1040)	None	Alcohol (ND)	AFFF (collapse) Protein (collapse) Fluoroprotein (collapse) Surfactant L (collapse) Surfactant H (untested)
	Liquefied Natural Gas (Methane) (1972)	Surfactant H (ND)	None	AFFF (early breakthrough) Alcohol (early breakthrough) Fluoroprotein (early breakthrough) Protein (early breakthrough) Surfactant L (early breakthrough)
INORGANICS	Carbon Disulfide (1131)	Hazmat NF #2 MSA Type V (ND)	None	AFFF (untested) Alcohol (untested) Fluoroprotein (untested) Protein (early breakthrough) Surfactant H&L (untested)

(continued)

TABLE 1 (continued)

GROUP	CHEMICAL (DOT No.)	RECOMMENDED FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	SATISFACTORY FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	INEFFECTIVE/ DANGEROUS FOAM TYPES (Reason)
INORGANICS (cont.)	Hydrochloric Acid (1050)	Hazmat NF #2 MSA Type V (ND)	None	AFFF (untested) Alcohol (untested) Fluoroprotein (untested) Protein (untested) Surfactant H&L (untested)
	Hydrogen Chloride (Anhydrous) (1050)	Hazmat NF #2 MSA Type V (ND)	None	AFFF (untested) Alcohol (untested) Fluoroprotein (untested) Protein (untested) Surfactant H&L (untested)
	Nitric Acid (2032)	Hazmat NF #2 MSA Type V (ND)	None	AFFF (untested) Alcohol (untested) Fluoroprotein (untested) Surfactant H&L (untested)
	Silicon Tetrachloride (1818)	Surfactant H (ND)	None	AFFF (violent reaction) Alcohol (violent reaction) Fluoroprotein (violent reaction) Protein (violent reaction) Surfactant L (violent reaction)

(continued)

TABLE 1 (continued)

GROUP	CHEMICAL (DOT No.)	RECOMMENDED FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	SATISFACTORY FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	INEFFECTIVE/ DANGEROUS FOAM TYPES (Reason)
INORGANICS (cont.)	Sulfur Trioxide (1829)	Hazmat NF #2 Surfactant H (ND) MSA Type V (ND)	None	AFFF (violent reaction) Alcohol (violent reaction) Fluoroprotein (violent reaction) Protein (violent reaction) Surfactant L (violent reaction)
	Titanium Tetrachloride (1838)	Hazmat NF #2 MSA Type V (ND)	None	AFFF (untested) Alcohol (untested) Fluoroprotein (untested) Protein (untested) Surfactant H&L (untested)
	Ammonia (1005)	Surfactant H (30/10)	AFFF (8/5) Alcohol (8/5) Surfactant (8/5) Fluoroprotein (8/5) Protein (8/5)	None

(continued)

TABLE 1 (continued)

GROUP	CHEMICAL (DOT No.)	RECOMMENDED FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	SATISFACTORY FOAM TYPES (Minimum Thickness/ Reapplication Rate)(in.+/min.)*	INEFFECTIVE/ DANGEROUS FOAM TYPES (Reason)
INORGANIC CRYOGENS	Bromine and Chlorine (1744) and (1017)	Hazmat NF #2 Surfactant H MSA Type V (ND)	None	Other foams are ineffective on chlorine, causing accelerated boiloff of heavier-than-air chlorine gas.

* Reapplication times are generally based on the amount of time before a 1 percent vapor concentration by volume is established above the spill surface.

** No data are available for foam thickness or reapplication rate.

*** H = high-expansion surfactant foam; L = low-expansion or medium-expansion surfactant foam.

**** Hazmat NF #1, Hazmat NF #2, and MSA Type V are specified by name because they were designed for controlling hazardous vapors.

\+ 1 inch = 2.54 centimeters.

The recommended foam thicknesses and reapplication rates in columns 3 and 4 of the table were interpreted from graphs depicting "vapor concentration" of a given chemical on the y-axis and "time after foam application" on the x-axis (1). These graphs represent a common method of presenting the results of vapor control tests with foams.

The final column of the table shows foam types that are ineffective when applied to certain spilled materials. It also provides reasons for placing a particular foam type in this category. Some of the foam types were placed in this category because there are no test data to indicate their effectiveness in controlling certain chemical vapors. When using Table 1 at a spill site, the responsible party should be careful not to use foam on chemicals not listed in the table unless pre-response testing of the foam has been conducted.

Anyone using Table 1 to purchase foam concentrates should be aware that vapor suppression qualities differ among different brands of foam and among different brands of foam-generating equipment. Therefore, persons responsible for selecting foam concentrates should review the following subsection.

3.2 Foam Quality

Two important indicators of foam quality in relation to vapor control are the "expansion ratio" and the "quarter drainage time". The expansion ratio is a dimensionless number that expresses the ratio of the volume of foam to the volume of foam concentrate that produced the foam. Since the technology for foams is rapidly changing and values for expansion ratio are somewhat controversial, expansion ratios will be defined as follows:

- High-expansion: greater than 250:1
- Medium-expansion: between 20-250:1
- Low-expansion: less than 20:1

High-expansion foams can only be generated using high-expansion surfactant foam concentrates in combination with special foam-generating equipment. However, low- and medium-expansion foams can be generated using various combinations of foam types and foam nozzles. For example, a given brand of alcohol type foam concentrate may produce a medium-expansion foam with one nozzle and a low-expansion foam using a different nozzle. Another brand of alcohol type foam may produce a medium-expansion foam with both nozzles.

In general, medium-expansion foams are the most effective foams for controlling vapors from spilled chemicals (4,6,10, 27). They are more easily applied to spills than high-expansion foams, and are not as easily displaced by wind. Furthermore, they generally have longer quarter drainage times than low-expansion foams and do not need to be reapplied as often.

The term "quarter drainage time" refers to the time it takes for a foam to release 25 percent of the total liquid incorporated into the foam. Long quarter drainage times are indicative of stable foams, which are capable of

supressing vapors from spilled chemicals for long time periods before re-application is necessary (assuming the foam is compatible with the spilled chemical). High-expansion foams exhibit the longest quarter drainage times, often exceeding one hour. However, these foams are not always recommended because they may be either incompatible with the spilled material (See Table 1) or they may be easily blown away in windy conditions. Medium-expansion foams exhibit quarter drainage times exceeding 15 minutes, but usually less than 30 minutes. Quarter drainage times for low-expansion foams, except AFFF foams, generally range between 3 and 12 minutes. Quarter drainage times for AFFF foams are also between 3 and 12 minutes, but the test procedures for AFFF foams are different than those used for the other foam types (28).

Expansion ratio and quarter drainage time are determined by standard tests described in the National Fire Codes (NFPA Standards 11 and 11A) and in Underwriters Laboratories' UL 162 (2,28,29). The tests for both of these parameters begin when foam is discharged from a standard distance onto a sloped backboard structure which drains into either a pan or a graduated cylinder (Figure 1). The graduated cylinder, shown in the top half of Figure 1, was incorporated into the standard expansion and drainage tests for exclusive use on AFFF foams due to their rapid drainage rates. Quarter drainage times for the other foam types are measured using a pan, as shown in the bottom half of Figure 1 (28).

Quarter drainage time is determined by plotting on a graph the volume of water drainage over time, and then interpolating the time when one-quarter of the water has been lost from the foam. Expansion ratio is determined by weighing the foam in the collection container and dividing this weight into the weight of an equivalent volume of water (23).

In determining quarter drainage times and expansion ratios of foams, it is important to consider the type of foam nozzle used to conduct the tests (4). The same batch of a given foam concentrate may display widely differing test results when different nozzles are used. Therefore, it is important to determine whether the nozzle used to produce the desired foam quality is available to the person applying the foam in the field.

One method of ensuring the selection of a reasonably high-quality foam without comparing expansion ratios and drainage times is to check the Underwriters Laboratories (UL) listings in the book entitled "Fire Protection Equipment Directory" (5). Although the book does not address vapor control, it lists all foams that passed the UL 162 tests for fire knockdown and burnback resistance. It also lists the specific combinations of liquid concentrates and equipment that have been tested and gives UL minimum performance standards for the tests. UL has also reviewed manufacturer's test reports and can recommend test procedures for a particular foam (28).

In the UL 162 tests, a 50-sq. ft. pan containing a specified test material is ignited and allowed to burn for 1 minute. Next, the fire is extinguished with foam and a lighted torch is moved over the entire foam blanket,

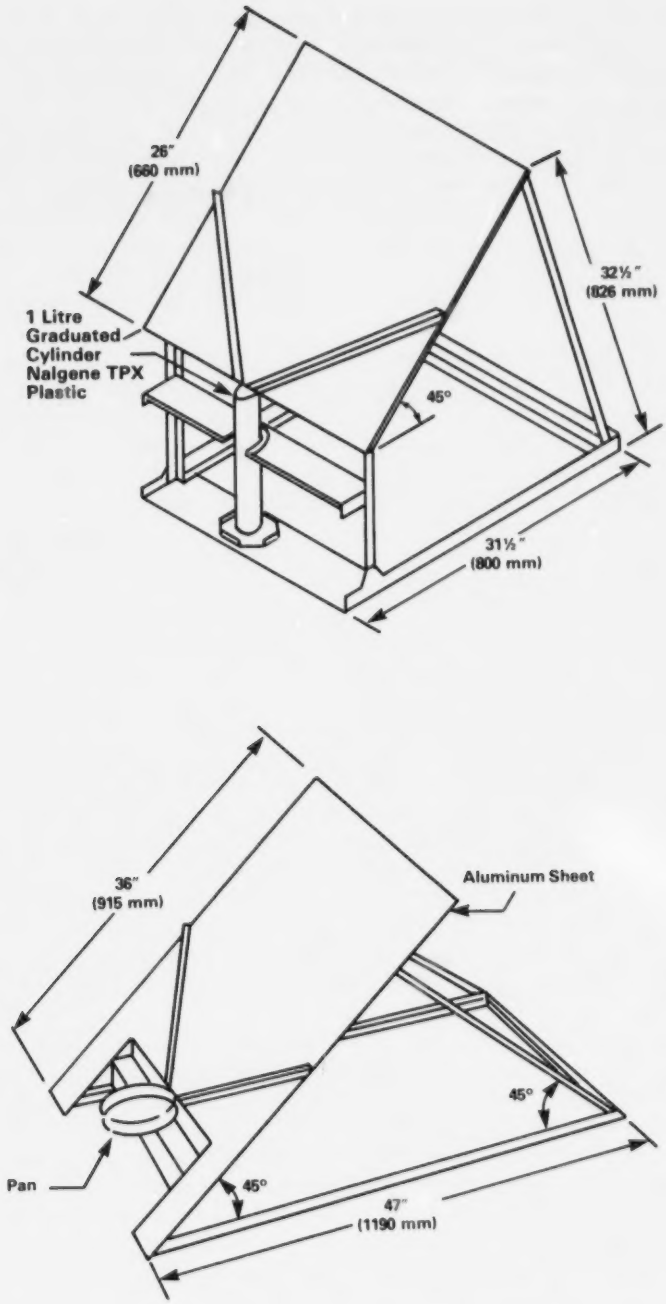

Figure 1: Typical standard backboard structures for collection of foams prior to testing for quarter drainage time and expansion ratio (according to Underwriters Laboratories, 1983).

approximately 1 inch above the foam, for either 9 minutes (AFFF foams only) or 15 minutes (all other foam types). To pass the torch portion of the test, there must be no candling, flaming, or flashing in excess of 30 seconds duration. This handbook provides a description of only part of the UL 160 test procedure. A full description of this procedure is available from Underwriters Laboratories, Northbrook, Illinois (28). All foams that pass the torch portion of this test would be beneficial in controlling vapors from the chemicals that were successfully tested. However, the best brand of foam for a given chemical can be identified only by comparing quarter drainage times and expansion ratios of representative foams from the foam types that are recommended in Table 1.

Comparisons of drainage times and expansion ratios between recommended types of foam are valid only when high-expansion foam is not involved in the comparison. High-expansion foams do not have the same flow characteristics and physical properties as low-expansion foams; therefore, without knowing site conditions, it is difficult to predict when they would be superior or inferior to low-expansion foams. It is recommended that a responder to a spill use proportioners, foam concentrates, and nozzles that are listed and approved by Underwriters Laboratories or Factory Mutual Research Corporation (5,30).

The importance of using quarter drainage time and expansion ratio to select a foam should be emphasized. Manufacturers do not always put these specifications on their labels, so responders should evaluate foams through inexpensive and easy-to-conduct tests for quarter drainage time and expansion ratio.

4. SUGGESTIONS FOR APPLYING FOAMS FOR VAPOR CONTROL

This section is a compendium of suggestions on when, where, and how to apply foams for vapor control.

4.1 Equipment

Fog nozzles should not be used to apply foams for vapor control. Fog nozzles typically reduce the expansion ratio of the foam by at least 50 percent, which also reduces its drainage time (6). Use foam nozzles that minimize drainage and maximize expansion of the foam. These can be either straight stream or spray nozzles, and either turret-mounted or hand-held. All nozzles are air aspirating (6).

Because medium-expansion foams are becoming available, there are fewer hard and fast rules regarding the size of nozzles to use for producing foam. Therefore, quarter drainage time becomes an increasingly important criterion for selecting a particular brand of foam. Nozzles may vary; thus foams should be tested with particular nozzles to produce the desired effects. The nozzle must match the eductor for proper foaming to occur (4).

4.2 Application of Medium-Expansion and High-Expansion Foams

High-expansion foams cannot be emplaced by a nozzle. They must be directed onto the spill using a foam chute or other conveying device. Winds over 10 miles per hour preclude their use unless a foam fence is available for corralling the foam over the spilled material. Even when a fence is used, these foams should not be considered for use when wind velocities exceed 20 miles per hour.

The application rate for high-expansion foams should be maximized and should exceed 0.5 cubic feet per minute for every square foot of spill area. The depth of high-expansion foams over flammable liquid spills should be greater than or equal to 18 inches. This depth is sufficient to keep the concentration of most vapors beneath or within the Lower Explosive Limit (LEL)(6).

4.3 Application of Low-Expansion Foams

When using a foam pumper, low-expansion foams can be discharged for maximum distances between 30 and 200 feet, depending on the nozzle size and

the water pressure used (31). These distances can also be achieved by using an eductor; however, water pressure must remain constant at the junction to the eductor. In general, foams should be directed to a point just in front of the spilled chemical, or to a wall behind the spilled chemical. This ensures that the foam will flow across the surface of the chemical and maintain its structural integrity (9). Careful application is especially important when using alcohol type foams, which separate into phases upon contact with polar solvents. Plunging these foams into a spill could result in little or no vapor mitigation due to multiple breaks in the lower foam layer (6).

The application rate of low-expansion foams for vapor control is not as critical as that for high-expansion foams because low-expansion foams can be applied rapidly with respect to mass/time (6). Assuming there is no fire and that the foam type is compatible with the spilled material, the foam will be destroyed only at a low rate, thus making the application rate even less critical. However, response organizations should attempt to cover a spill as gently and as rapidly as their equipment will allow without creating turbulence because the release of toxic and/or flammable gases will continue until the entire spill area is covered. The capabilities of equipment and foam can be determined by using the following formula:

$$T = \frac{0.748DA}{RE} \qquad 4\text{-}1$$

Where:

T = Desired time of coverage in minutes
D = Desired foam depth in feet
A = Area of the spill in square feet
R = Discharge capacity of existing equipment in gallons per minute of foam concentrate/water mixture
E = Expansion of foam (e.g., 6,7,7.5,8,...).

For example, this formula estimates that one 65 gpm nozzle could cover a 1,330-sq. ft. spill area in under 1 minute, assuming a foam expansion ratio of 8:1 and a desired foam depth of 6 inches.

In addition to determining the amount of time for covering different size spills, it is important to estimate the spill sizes that can be mitigated by each type of foam to be carried on a response vehicle. To estimate this amount, decide how much of each foam type will be carried on the response vehicle. Next, calculate the maximum area to be mitigated by each foam by the following formula:

$$A = \frac{100\ EC}{7.48\ DP} \qquad 4\text{-}2$$

Where:

A = Area of spill in square feet
E = Expansion ratio of the foam used
C = Gallons of foam concentrate in response vehicle
D = Desired foam depth in feet
P = Percentage shown on container of foam concentrate (a concentration).

For example, if a response vehicle could carry 25 gallons of 3 percent alcohol foam, it would be capable of covering a 2,670-sq. ft. acetone spill, assuming a foam expansion ratio of 8 and a desired foam depth of 4 inches. According to Table 1, the foam blanket on acetone would need to be reapplied after one hour. Therefore, more than 25 gallons of foam concentrate would be needed for a spill of this size lasting over 1 hour.

4.4 Special Considerations

Foams should never be applied for vapor control on materials that have not been tested. In general, they should not be used on liquefied gases (except chlorine and bromine) that are heavier than air (e.g., butane, propane, butadiene) because they may cause accelerated formation of vapor clouds that stay close to the ground and flow to low-lying areas (6).

Foam life is finite; thus, with spills that require a long cleanup period, foams must be reapplied in order to maintain their desired thicknesses. Therefore, it is important to have enough foam on hand to complete the foam layer and to reapply the foam as necessary.

Foams covering flammable liquids can develop gas mixtures within the bubbles within flammable/explosive range and such foams can rapidly deflagrate if presented with an ignition source. This will usually result in ignition and fire of the liquid pool covered by the foam.

The control of vapors by the use of foams should not be undertaken without proper protective gear. Similarly, protective gear, such as a self-contained breathing apparatus, should never be removed after foam application because it is impossible to predict the degree of vapor mitigation at a site in terms of human toxicity. It is also impossible to precisely predict the foam effectiveness time. Therefore, reapplication times of foams must be established on-scene through periodic visual inspections of the foam blanket (6). For flammable vapors, protective clothing is necessary, and one can determine when to reapply the foam by monitoring the spill continuously with an explosimeter.

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APPENDIX

FACTORS FOR UNIT CONVERSION

Unit	Multiply by	To find
inch	2.54	centimeters
foot	30.48	centimeters
foot	0.30	meters
yard	0.90	meters
cubic foot per second	448.8	gallons per minute
square foot	0.09	square meters

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